

# Description

## OCCUPANT SENSOR

### CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The instant application is a division of U.S. Application Serial No. 09/866,885 filed on May 29, 2001, now pending, which claims the benefit of U.S. Provisional Application Serial No. 60/207,536 filed on May 26, 2000. The above-identified applications are incorporated herein by reference. The following commonly owned patent applications are incorporated herein by reference: U.S. Application Serial No. 09/474,600 entitled Occupant Detection System, filed on December 29, 1999 ("ASL-222-US"); U.S. Application Serial No. 09/474,470 entitled Occupant Detection System, filed on December 29, 1999 ("ASL-228-US"); U.S. Application Serial No. 09/ 568,596 entitled Occupant Detection System, filed on May 10, 2000 ("ASL-234-US"); U.S. Application Serial No. 09/474,473 entitled Occupant Detection System, filed on December 29, 1999 ("ASL-257-US"); U.S. Application Serial No. 09/474,673 entitled Occupant Detection System, filed on December

29, 1999 ("ASL-258-US"); U.S. Application Serial No. 09/474,469 entitled Occupant Detection System, filed on December 29, 1999 ("ASL-259-US"); U.S. Application Serial No. 09/520,866 entitled Proximity Sensor, filed on March 6, 2000 ("ASL-225-US"); U.S. Application Serial No. 09/614,086 entitled Occupant Sensor, filed on July 11, 2000 ("ASL-236-US"); and U.S. Application Serial No. 09/616,406 entitled Proximity Sensor, filed on July 14, 2000 ("ASL-237-US").

## **BACKGROUND OF INVENTION**

[0002] *U.S. Patent No. 5,525,843* discloses a seat occupant detection system that uses a seat heater element as an electrode of a capacitive sensor, wherein a pair of relay activated switches are used to either isolate or connect the heating element from or to the associated current supply and ground, wherein the heating element is isolated when sensing the occupant and is otherwise connected when heating the seat. One potential limitation with such an arrangement is that relay controlled switch elements may not be sufficiently reliable for safety applications, such as controlling the actuation of a safety restraint system.

## **BRIEF DESCRIPTION OF DRAWINGS**

[0003] In the accompanying drawings:

[0004] *FIG. 1* illustrates an embodiment of an occupant sensor in a seat with a seat heater;

[0005] *FIG. 2* illustrates another embodiment of an occupant sensor in a seat with a seat heater;

[0006] *FIG. 3* illustrates a plan view of a sensor electrode and a heating element of a seat heater in a seat bottom;

[0007] *FIG. 4* illustrates yet another embodiment of an occupant sensor in a seat with a seat heater;

[0008] *FIG. 5* illustrates yet another embodiment of an occupant sensor in a seat with a seat heater;

[0009] *FIG. 6* illustrates yet another embodiment of an occupant sensor in a seat with a seat heater;

[0010] *FIG. 7* illustrates yet another embodiment of an occupant sensor in a seat with a seat heater;

[0011] *FIG. 8a* illustrates a schematic diagram of an embodiment of a circuit for providing both amplitude and phase information from an electric field sensor;

[0012] *FIG. 8b* illustrates the operation of various elements of the sensing circuit of *FIG. 8a*;

[0013] *FIGs. 9a* and *9b* illustrate a schematic diagram of another embodiment of a circuit for providing both amplitude and phase information from an electric field sensor;

- [0014] *FIG. 10* illustrates a schematic diagram of an embodiment of a circuit for providing both integral and peak information from an electric field sensor using pulse excitation;
- [0015] *FIG. 11* illustrates a schematic diagram of another embodiment of a circuit for providing both integral and peak information from an electric field sensor using pulse excitation;
- [0016] *FIG. 12* illustrates a child in a typical rear facing infant seat placed on a vehicle seat; and
- [0017] *FIG. 13* illustrates a plan view of a heating element of a seat heater in a seat bottom, wherein the heating element is used as an electrode of an electric field sensor and is shaped for reduced sensitivity proximate a central region of the seat bottom.

#### **DETAILED DESCRIPTION**

- [0018] A vehicle may contain safety restraint actuators that are activated responsive to a vehicle crash for purposes of mitigating occupant injury. Examples of such automatic safety restraint actuators include air bags, seat belt pretensioners, and side curtains. One objective of an automatic restraint system is to mitigate occupant injury, thereby not causing more injury with the automatic restraint system than would be caused by the crash had the

automatic restraint system not been activated. Generally, it is desirable to only activate automatic safety restraint actuators when needed to mitigate injury because of the expense of replacing the associated components of the safety restraint system, and because of the potential for such activations to harm occupants.

[0019] One technique for mitigating injury to occupants by the air bag inflator is to control the activation of the inflator responsive to the presence and/or position of the occupant, thereby activating the inflator only when an occupant is positioned outside an associated at-risk zone of the inflator. NHTSA data suggests that severe injuries due to close proximity with the inflator can be reduced or eliminated if the air bag is disabled when the occupant is closer than approximately 4 to 10 inches from the inflator door. Such a system for disabling the air bag inflator requires an occupant sensor that is sufficiently sensitive and robust to make such a determination, while not causing the air bag inflator to be disabled when otherwise required for providing occupant restraint.

[0020] One technique for detecting the presence and/or position of an occupant is by sensing the influence of an occupant upon an electric field generated proximate to a seat for

which the presence and/or position. An occupant has associated dielectric and conductive properties that can influence an electric field, and accordingly the occupant is an electric-field-influencing medium that can be detected with an electric field sensor sometimes also known as a capacitive sensor.

[0021] As used herein, the term "electric field sensor" refers to a sensor that generates a signal responsive to the influence of a sensed object upon an electric field. Generally, an electric field sensor comprises at least one electrode to which is applied at least one applied signal; and at least one electrode which could be the same electrode or electrodes to which the applied signal is applied at which a received signal (or response) is measured. The applied signal generates an electric field from the at least one electrode to a ground in the environment of the at least one electrode, or to another at least one electrode. The applied and received signals can be associated with the same electrode or electrodes, or with different electrodes. The particular electric field associated with a given electrode or set of electrodes is dependent upon the nature and geometry of the electrode or set of electrodes and upon the nature of the surroundings thereto, for example

the dielectric properties of the surroundings. For a fixed electrode geometry, the received signal or signals of an electric field sensor are responsive to the applied signal or signals and to the nature of the environment influencing the resulting electric field, for example to the presence and location of an object with a permittivity or conductivity different to that of its surroundings.

[0022] One form of electric field sensor is a capacitive sensor, wherein the capacitance of one or more electrodes is measured from the relationship between received an applied signals for a given electrode configuration. The technical paper "Field mice: Extracting hand geometry from electric field measurements" by J. R. Smith, published in IBM Systems Journal, Vol. 35, Nos. 3 &4, 1996, pp. 587-608, incorporated herein by reference, describes the concept of electric field sensing as used for making non-contact three-dimensional position measurements, and more particularly for sensing the position of a human hand for purposes of providing three dimensional positional inputs to a computer. What has commonly been referred to as capacitive sensing actually comprises the distinct mechanisms of what the author refers to as "loading mode", "shunt mode", and "transmit mode" which corre-

spond to various possible electric current pathways. In the shunt mode, a voltage oscillating at low frequency is applied to a transmit electrode, and the displacement current induced at a receive electrode is measured with a current amplifier, whereby the displacement current may be modified by the body being sensed. In the "loading mode", the object to be sensed modifies the capacitance of a transmit electrode relative to ground. In the transmit mode, the transmit electrode is put in contact with the user's body, which then becomes a transmitter relative to a receiver, either by direct electrical connection or via capacitive coupling.

[0023] A seat-based capacitive sensor can be affected by seat heater when co-located in the same area of the seat as the seat heater. A seat heater is typically a low resistance conductor (i.e. approximately 1 Ohm) in an under layer of the seat cover. In operation, a direct current of several amperes is sent through the heater element to generate heat. The heater element appears to be a ground to a capacitive sensor measuring the impedance to ground with an oscillatory or pulsed voltage.

[0024] The above-noted problems may be overcome as described and claimed hereinbelow.



[0025] Referring to *Fig. 1*, an *occupant sensor 10* comprises an *electric field sensor 12* for detecting an occupant on a *seat 14* of a *vehicle 16*. The *electric field sensor 12* is, for example, placed in the *seat bottom 18* under a *seat cover 20* and close to the top of a *foam cushion 22*, but may be located elsewhere, for example in the *seat back 24*, for other occupant sensing applications.

[0026] The *seat 14* further incorporates a *seat heater 26* for heating the *seat 14* so as to provide a comfortable seating environment for the occupant. The *seat heater 26* is activated by an *ON-OFF switch 28*, and the temperature thereof is regulated, for example, by a *relay 30* under control of a *thermostat 32*. The *seat heater 26* comprises a *heating element 34*, for example, a resistive heating element, that is sufficiently conductive to either function as an electrode of an *electric field sensor 12*, or function as an electrode that could influence an *electric field sensor 12* proximate thereto.

[0027] Generally, the effects of any conductor -- including a separate *heating element 34* -- on a *electric field sensor 12* can be eliminated, or at least substantially reduced, by driving that conductor with a signal -- known as a *driven shield signal 36* having substantially the same potential variations (i.e. amplitude and phase) as an *applied signal 38* applied to

a *sensor electrode 40* of the *electric field sensor 12*. By driving the separate *heating element 34* with a *driven shield signal 36*, substantially no current flows between the *heating element 34* and a *sensor electrode 40* of the *electric field sensor 12* proximate thereto, thus making the *seat heater 26* element substantially invisible to the *capacitive sensor 12'*. Moreover, the *electric field sensor 12* and the *heating element 34* need not be at the same DC offset if the associated *sensing circuit 42* is responsive substantially only to an AC or pulsed component of a *sensed signal 44* from the *electric field sensor 12*.

[0028] One problem associated with driving the *seat heater 26* with a *driven shield signal 36* is that the *seat heater 26* typically has a relatively low impedance either to the *source of power 46* – i.e. the current source or vehicle battery or the *sink of power 48* – i.e. ground operatively connected to the *seat heater 26*. Without further modification, this would require the circuit driving the *seat heater 26* with the *driven shield signal 36* to have a relatively large current capability.

[0029] Referring to *Fig. 1*, one solution to this problem is to place relatively high current capacity *first 50* and *second 52* inductors in series with the *heating element 34*, respectively between the *heating element 34* and the *source of power 46*, and between the *heating element 34* and the *sink of power 48*,

wherein the inductance of the *first 50* and *second 52 inductors* is chosen such that their respective impedances are relatively high at the frequency, or frequencies of the *applied signal 38*, so that the *first 50* and *second 52 inductors* act as chokes thereto. Accordingly, because of the relatively high impedance *first 50* and *second 52 inductors*, the *driven shield signal 36* can be AC coupled to the *heating element 34* without being substantially loaded by the *source of power 46* or the *sink of power 48*.

[0030] The *electric field sensor 12* is either what is commonly known as a *capacitive sensor 12'*, or more generally an electric field sensor operating in any of the above described modes. The *electric field sensor 12* comprises at least one *sensor electrode 40* operatively coupled by a *bridge capacitor 54* to an *applied signal 38* generated by a *signal generator 55*, so as to generate an electric field proximate to the at least one *sensor electrode 40* responsive to the *applied signal 38*. The *applied signal 38* for example comprises either an oscillating or pulsed signal. As illustrated in *Fig. 1*, the *sensor electrode 40* is modeled as a parallel combination of a *capacitance  $C_s$*  and a *resistance  $R_s$* , to *circuit ground 56*. The series combination of the *bridge capacitor 54* and the *sensor electrode 40* acts as an *AC voltage divider 58*, whereby the AC signal level of

the *sensed signal 44* at the *node 60* therebetween is responsive to the impedance of the *sensor electrode 40*, which is in turn responsive to at least one electric-field-influencing property for example dielectric constant, conductivity, size, mass or distance -- of an object proximate to the *electric field sensor 12*. The *node 60* -- and the *sensed signal 44* thereat -- is operatively connected to an *input 62* of a voltage follower *buffer amplifier 64*, which *input 62* is DC biased by an associated *resistive divider network 66* between *power V+* and *circuit ground 56*. The *buffer amplifier 64* has the capacity to source and sink current so that the *output 68* therefrom the *driven shield signal 36* -- has substantially the same signal level as the *input 62* thereto. The *driven shield signal 36* is AC coupled through a *coupling capacitor 70* to the *heating element 34* of the *seat heater 26* so as to electrically shield the *sensor electrode 40* from its surroundings on the *heating element 34* side thereof.

[0031] The *output 68* of the *buffer amplifier 64* is also operatively connected to a *sensing circuit 42* that provides gain, band-pass filtering, signal detection, low-pass filtering, DC offset adjustment and DC gain so as to recover a DC signal responsive to the impedance of the *electric field sensor 12*, as is described in greater detail hereinbelow. The *sensing cir-*

*cuit 42* provides a measure responsive to the impedance of the *sensor electrode 40*, and the output therefrom is operatively coupled to a *controller 74* that determines a seat occupancy condition -- e.g. occupant presence, type, size or position -- from that measure and outputs either an enable signal or a disable signal to one input of an *AND gate 76*. The other input of the *AND gate 76* is operatively connected to a *crash detector 78* that detects whether or not the *vehicle 16* has been involved in a crash of sufficient severity to warrant the deployment of a *safety restraint actuator 80*.

[0032] The *sensor electrode 40* may be shaped and located so as to be able to distinguish seating conditions for which a *safety restraint actuator 80*, for example an air bag inflator module, should be deployed from seating conditions for which the *safety restraint actuator 80* should not be deployed so as to avoid causing more injury to an occupant than the occupant would otherwise incur without the deployment of the *safety restraint actuator 80*. For example, the *sensor electrode 40* is shaped and located so that a capacitance of the at least one *sensor electrode 40* with respect to a *circuit ground 56* is substantially greater for a seating condition for which the *safety restraint actuator 80* should be deployed, for example an occupant seated in substantially normal seat-

ing position on the *seat 14* or a large body immediately above the *seat bottom 18*; than for a seating condition for which the *safety restraint actuator 80* should not be deployed, for example an empty *seat 14*, an infant, child, or booster seat on the *seat 14* with or without an infant or child seated therein, or an occupant on the *seat 14* in a position that is substantially different from a normal seating position. The *sensor electrode 40* is, for example, substantially the same size as a region to be sensed on the *seat 14*, and sections of the *sensor electrode 40* may be removed to selectively reduce the sensitivity thereof proximate to regions where an infant or child, in an infant, child, or booster seat, is closest to the *seat 14*.

[0033] The *sensor electrode 40* may be constructed in a variety of ways, and the method of construction is not considered limiting. For example, an electrode may be constructed using rigid circuit board or a flexible circuit using known printed circuit board techniques such as etching or deposition of conductive materials applied to a dielectric substrate. Alternately, an electrode may comprise a discrete conductor, such as a conductive film, sheet or mesh that is distinct from or an integral part of the *seat 14* or components thereof. The assembly of one or more electrodes

together with the associated substrate is sometimes referred to as a sensing pad or a capacitive sensing pad.

[0034] In operation, the *signal generator 55* generates an oscillatory or pulsed *applied signal 38* that is applied across the *AC voltage divider 58* comprising the *bridge capacitor 54* and the *sensor electrode 40*. A *sensed signal 44* at the *node 60* of the *AC voltage divider 58* is buffered by the *buffer amplifier 64* which outputs a *driven shield signal 36* of substantially the same magnitude and phase as the *sensed signal 44*. The *driven shield signal 36* is applied through a *coupling capacitor 70* to the *heating element 34* of a *seat heater 26* proximate to and below the *sensor electrode 40* in the *seat 14*. The *first 50* and *second 52 inductors* choke the *driven shield signal 36* so as to prevent either the *source of power 46* to or the *sink of power 48* from the *seat heater 26* from excessively loading the *buffer amplifier 64*. The *applied signal 38* coupled to the *sensor electrode 40* causes the *sensor electrode 40* to generate an electric field that couples with the surroundings thereof. The *driven shield signal 36* applied to the *heating element 34* substantially nulls the electric field between the *sensor electrode 40* and the *heating element 34*, which substantially isolates the *sensor electrode 40* from influence by portions of the *seat 14* on the same side as the *seat heater 26* relative to

the *sensor electrode 40*.

[0035] An occupant seated on the *seat 14* increases the capacitance of the *sensor electrode 40*, which decreases the capacitive reactance thereof so as to reduce the magnitude of the *sensed signal 44* at the *node 60* of the *AC voltage divider 58*. The *sensed signal 44* is operatively coupled to the *sensing circuit 42* through the *buffer amplifier 64*. The *sensing circuit 42* conditions and detects a measure responsive to the impedance of the *sensor electrode 40*, from which the *controller 74* detects the associated seat occupancy condition. If the seat occupancy condition warrants the actuation of a *safety restraint actuator 80* responsive to a crash e.g. for a normally seated adult occupant for which the associated capacitance is greater than a threshold -- then the *controller 74* outputs an enable signal (TRUE) to the *AND gate 76*. Otherwise e.g. for an out-of-position occupant, a physically small occupant, or rear-facing-infant seat for which the associated capacitance is less than a threshold -- the *controller 74* outputs a disable signal (FALSE) thereto. For the example of a *safety restraint actuator 80* comprising an air bag inflator module, responsive to a crash detected by the *crash detector 78*, if an occupant is seated on the *seat 14*, an actuation signal from the *con-*



*troller 42* is operatively coupled to one or more *initiators* of one or more *gas generators* mounted in the *air bag inflator module*, thereby controlling the actuation of the *air bag inflator module 42* so as to inflate an associated *air bag 60* as necessary to protect the occupant from injury which might otherwise be caused by the crash. The electrical power necessary to carry out these operations is provided by a *source of power 46*, for example, the vehicle battery.

[0036] The above-described circuitry may be either integrated in one module, or embodied in a plurality of modules. For example, the *sensing circuit 42* and *controller 74* may be combined with the *signal generator 55* and other circuit elements in a single module that provides all of the above described functions. This single module may further incorporate the *crash detector 78*. Alternately, the *controller 74* and/or *crash detector 78* may be embodied as a separate element or as separate elements that communicate with the remaining circuit elements in a separate module.

[0037] Referring to *Fig. 2*, another method of mitigating the influence of a *heating element 34* on a *capacitive sensor 12'* is to shield the conductor of the *heating element 34* with a *conductive shield 82* located between the *heating element 34* and the *sensor electrode 40*, wherein the *conductive shield 82* is driven

by a *driven shield signal 36*. The *conductive shield 82, 82'* may also be adapted to surround the *heating element 34*, similar to how the shield of a coaxial cable surrounds the center conductor. The *heating element 34*, for example, in the form of a heating cable, may be surrounded by a conductive sheath that is operatively coupled to the *driven shield signal 36*.

[0038] For either of the configurations illustrated in *Figs. 1 and 2*, the *sensor electrode 40* is located either between the occupant seating area and the *heating element 34*, or, as illustrated in *Fig. 3*, is inter-digitized on a common substrate with the *heating element 34*, so that the *sensor electrode 40* is not shielded from the occupant by the *heating element 34*.

[0039] Referring to *Fig. 4*, the above-described system of *Fig. 1* may be modified to utilize the conductive *heating element 34* of the *seat heater 26* as the *sensor electrode 40* of the *electric field sensor 12*, wherein the *heating element 34* is AC coupled to the *node 60* of the *AC voltage divider 58* by a *coupling capacitor 84* so that the DC offset from the heater element does not affect the resulting sensor measurement. In this case, the *driven shield signal 36* is not separately coupled to the *heating element 34* as in the embodiment of *Fig. 1*. The *coupling capacitor 84* preferably has a capacitance at least

ten times larger than the capacitance of the *sensor electrode 40* to ground so that the effect thereof on the *AC voltage divider 58* output is relatively small. This circuit becomes practical when the frequencies used to make the measurement are for example above 1 MHz (and preferably above 10 MHz) -- depending upon the cost and size of inductors -- such that the inductance of the inductors can be less than 100 micro-Henries.

[0040] A *driven shield 85* may be provided on the side of the *heating element 34* away from the seating area, which when operatively coupled to the *driven shield signal 36* would substantially reduce the coupling of the *applied signal 38* to that portion of the seat that is away from the seating area.

[0041] In operation, the *signal generator 55* generates an oscillatory or pulsed *applied signal 38* that is applied across the *AC voltage divider 58* comprising the *bridge capacitor 54* and the AC coupled *heating element 34* that acts as *sensor electrode 40*. A *sensed signal 44* at the *node 60* of the *AC voltage divider 58* is buffered by the *buffer amplifier 64*. The *first 50* and *second 52 inductors* choke the *driven shield signal 36* so as to prevent either the *source of power 46* to or the *sink of power 48* from the *seat heater 26* from substantially influencing the capacitance of the *sense electrode 40*. The *applied signal 38* coupled

to the *heating element 34* causes the *heating element 34* to generate an electric field that couples with the surroundings thereof.

[0042] An occupant seated on *seat 14* increases the capacitance of the *heating element 34*, which decreases the capacitive reactance thereof so as to reduce the magnitude of the *sensed signal 44* at the *node 60* of the *AC voltage divider 58*. The *sensed signal 44* is operatively coupled to the *sensing circuit 42* through the *buffer amplifier 64*, and is subsequently processed and used as described hereinabove for the embodiment of *Fig. 1*.

[0043] Whereas *Figs. 1* and *4* illustrate the input of the the *sensing circuit 42* as being operatively coupled to the *output 68* of the *buffer amplifier 64*, it should be understood that the input of the the *sensing circuit 42* could alternately be operatively connected to the *input 62* thereof.

[0044] Referring to *Fig. 5*, in accordance with another embodiment, the *heating element 34* is used as the *sensor electrode 40* and a *driven shield signal 36* is used to electrostatically isolate the *sensor electrode 40* from both the *source of power 46* and the *sink of power 48* that are used to power the *seat heater 26*. As with the embodiments illustrated in *Figs. 1* and *4*, a *first impedance 86* is operatively connected between

a *first node 88* of the *heating element 34* and the *source of power 46* (e.g. vehicle battery); and a *second impedance 90* is operatively connected between a *second node 92* of the *heating element 34* and the *sink of power 48* (e.g. vehicle ground). Further to the embodiments illustrated in *Figs. 1* and *4*, a *third impedance 94* is operatively connected between the *first impedance 86* and the *source of power 46*, wherein the *first impedance 86* and the *third impedance 94* are operatively connected in series with one another at a *third node 96*. Moreover, a *fourth impedance 98* is operatively connected between the *second impedance 90* and the *sink of power 48*, wherein the *second impedance 90* and the *fourth impedance 98* are operatively connected in series with one another at a *fourth node 100*. As with the embodiment illustrated in *Fig. 4*, an oscillatory or pulsed *applied signal 38* is generated by a *signal generator 55* and applied to the *sensor electrode 40* through a *bridge capacitor 54* of an *AC voltage divider 58*, and through a *coupling capacitor 84*; and the resulting *sensed signal 44* at the *node 60* of the *AC voltage divider 58* is operatively connected to a *sensing circuit 42* and to a *buffer amplifier 64* that provides a *driven shield signal 36* at the output thereof. The *driven shield signal 36* is AC coupled through respective *coupling capacitors 70.1, 70.2* to the *third 96* and

*fourth 100 nodes*, which electrostatically shields the *heating element 34* from the *source of power 46* and the *sink of power 48* respectively. Both sides of the *first 88* and *second 90 impedances* are each respectively driven at substantially the same signal level, so that substantially no current flows therethrough responsive to the *applied 38* and *driven shield 36 signals*. The *third 94* and *fourth 98 impedances* are each adapted to choke or block current responsive to the *driven shield 36 signal* to or from the *source 46* or *sink 48 of power* respectively. Accordingly, the *sensor electrode 40* is substantially electrostatically isolated from the *source 46* or *sink 48 of power*, and is principally responsive to electric-field-influencing media, such as an occupant, proximate thereto. The *first 86*, *second 90*, *third 94* and *fourth 98 impedances* comprise circuit elements that have a relatively low impedance to the *source of power 46*, e.g. a DC power supply, but which either have a relatively high impedance to a signal generated by the *signal generator 55*, either continuously or intermittently. Examples of circuit elements exhibiting this property include inductors, and electronic switches such as field-effect transistors, as illustrated in the embodiments of *Figs. 6* and *7* respectively.

[0045] Referring to *Figs. 6* and *7*, which illustrate examples of par-

ticular embodiments of the generalized circuit illustrated in *Fig. 5*, the *signal generator 55* comprises an *oscillator 102* that is AC coupled through a *coupling capacitor 104* to a *buffer amplifier 106*, the input of which is DC biased by a *DC voltage divider 108*. A pair of *diodes 110* operatively connected to the *node 60* of the *AC voltage divider 58* clip the noise signal level so as to not exceed a range bounded by the *power supply voltage V+* and ground.

[0046] Referring to *Fig. 6*, the *first 86*, *second 90*, *third 94* and *fourth 98 impedances* are provided by *inductors 112, 114, 116 and 118* respectively, each having 1) a current carrying capacity sufficient to handle the current necessary to power the *seat heater 26*, 2) a relatively low DC impedance, and 3) a relatively high impedance at the frequency of the *oscillator 102*.

[0047] Referring to *Fig. 7*, the *first 86*, *second 90*, *third 94* and *fourth 98 impedances* are provided by *field-effect transistors 120, 122, 124 and 126* respectively each having a sufficient current carrying capacity to handle the current necessary to power the *seat heater 26*. The respective gates of the *field-effect transistors 120, 122, 124 and 126* are driven through respective *resistors 128* by a *control signal 129* from the *sensing circuit 42*, wherein the *control signal 129* at a low level turns the

*field-effect transistors 120, 122, 124 and 126* OFF when sensing the *sensed signal 44*, and, at a high level, otherwise turns the *field-effect transistors 120, 122, 124 and 126* ON to enable the *seat heater 26* to generate heat when both the *ON-OFF switch 28* and the thermostatically controlled *relay 30* are activated. The *field-effect transistors 120, 122, 124 and 126* are generally characterized by associated gate-source and gate-drain capacitances, that unless otherwise compensated, could act to bypass a portion of the *applied signal 38* through associated gate control circuits. This problem can substantially eliminated by AC coupling the *driven shield signal 36* to the respective gates of the *field-effect transistors 120, 122* associated with the *first 86 and second 90 impedances*, wherein the source, drain and gate of each respective *field-effect transistor 120, 122* are driven at substantially the same AC signal level, which accordingly should not cause these *field-effect transistor 120, 122* to either turn on or off responsive thereto. The resistors shown between the source and drain of the respective *field-effect transistors 120, 122, 124 and 126*, and across the *ON-OFF switch 28* and the switch controlled by the *thermostat 32* provide a D.C. reference for the *control signal 129* to the gates of the respective *field-effect transistors 120, 122, 124 and 126*.



[0048] In accordance with another embodiment, the *first 86* and *second 90 impedances* could be embodied by respective *field-effect transistors 120* and *122* as described hereinabove with reference to *Fig. 7*, and the *third 94* and *fourth 98 impedances* could be embodied by respective *inductors 116* and *118* as described hereinabove with reference to *Fig. 6*. Alternately, the *first 86* and *second 90 impedances* could be embodied by respective *inductors 112* and *114* as described hereinabove with reference to *Fig. 6*, and the *third 94* and *fourth 98 impedances* could be embodied by respective *field-effect transistors 124* and *126* as described hereinabove with reference to *Fig. 7*.

[0049] For purposes of illustration, and by way of example only, an *electric-field-sensor circuit 130* was constructed incorporating a *bridge capacitor 54* having a capacitance of 54 pico-Farads, and a *coupling capacitor 84* having a capacitance of .01 micro-Farads. The frequency of the *applied signal 38* is adapted to be sufficiently high such that the associated capacitive reactance  $Z(C_s)$  of the *sensor electrode 40* is substantially less than the *resistance  $R_s$*  thereof, for example, greater than or equal to 400 kilo-Hertz. With a 400 kilo-Hertz sinusoidal *applied signal 38*, *inductors 112, 114, 116* and *118* having respective inductances of 100 micro-Henries

or less can provide sufficient isolation for the embodiments illustrated in *Figs. 1, 5 and 6*. The embodiment illustrated in *Fig. 4* would possibly incorporate either a higher operating frequency, larger inductance values, or both. The output impedance of the *buffer amplifier 64* providing the *driven shield signal 36* is, for example, relatively low compared with the associated *first 86, second 90, third 94 or fourth 98 impedances*, the later of which depend upon the frequency of the *applied signal 38*.

[0050] The above-described system and method for co-locating a capacitive sensor with a heater element can also be applied when co-locating a capacitive sensor with other sensors below the occupant, including weight sensors (load cells and force sensitive resistors), and pressure pattern sensors (force sensitive resistors and bend sensors). For example, the capacitive sensor in the seat bottom could be integrated with either a force sensing resistors sensor or a bend sensor using a common sensing mat, pad or substrate.

[0051] The *sensing circuit 42* illustrated *Figs. 1, 4, 5, 6 and 7* is part of a larger circuit that will be referred to herein as an *electric-field-sensor circuit 130*, wherein the latter includes for example the *signal generator 55, AC voltage divider 58, buffer am-*

*plifier 64, sensing circuit 42, and other related components. Figs. 8a, 8b, 9a, 9b, 10 and 11 illustrate various embodiments of the electric-field-sensor circuit 130, which are now described in further detail, wherein the labels SENSOR and DRIVEN SHIELD are used to indicate common signal locations where the electric-field-sensor circuits 130, or portions thereof, of Figs. 8a, 8b, 9a, 9b, 10 and 11 would interface with the systems illustrated in Figs. 1, 4, 5, 6 and 7.*

[0052] The temperature range that is possible in an automotive environment can potentially adversely affect the *electric-field-sensor circuit 130*, causing a drift in the "perceived" sensor reading. One simple way to combat this drift is to use a reference capacitor that can be switched into the measurement circuit in place of the sensing electrode. Because the reference capacitor can be selected such that its value is relatively stable over temperature, drift can be identified and this information can be used to alter a decision threshold. An alternative scheme is to always measure the difference between a reference capacitor and the sensor capacitance. A second "calibration" capacitor can then be switched in to take the place of the sensor to identify the measurement system gain. Using a reference capacitor and a calibration capacitor allows the system to

continuously compensate for variations in the measurement circuit. Rather than attempting to measure the temperature and then make a correction, the reference and calibration capacitor are used to measure the current offset and gain of the measurement circuitry so that measurements are always consistent. Switching between the reference capacitor, the calibration capacitor, or a sensor can be done using a combination of FET's or an analog demultiplexor such as a CD4051 from Texas Instruments.

[0053] The capacitance of the *sensor electrode 40* relative to *circuit ground 56* is relatively small, for example less than about 300 pico-Farads. The temperature range that is possible in an automotive environment can significantly affect the components of the *electric-field-sensor circuit 130*, causing drift that can be erroneously interpreted as a measurement that could enable the *safety restraint actuator 80* to be erroneously enabled by the *controller 74*. The effects of this drift can be mitigated by incorporating a temperature stable reference capacitor in the *electric-field-sensor circuit 130* that is switched in place of the *sensor electrode 40* so as to provide a means for making comparative capacitive measurements. Since the reference capacitor can be selected such that its value is very stable over temperature, drift

can be identified and quantified, and this information can be used to alter a decision threshold, for example responsive to a drift in circuit elements of the *electric-field-sensor circuit 130* with respect to temperature or time.

[0054] Referring to *Fig. 8a*, illustrating an exemplary *electric-field-sensor circuit 130*, an *oscillator 1002* generates an oscillating signal, for example a sinusoidal signal, that is filtered by a *first bandpass filter 1004* so as to create a *first oscillating signal 1006*. The *first oscillating signal 1006* is applied to a *capacitive voltage divider 1008* comprising *capacitor C1*, *resistors R1* and *R2*, and one or more capacitive elements to be measured, selected from the group consisting of the *sensor electrode 40*, comprising at least one *sensor electrode 40*, a *first reference capacitor CR1*, and a *second reference capacitor CR2*, wherein the capacitive elements to be measured are included or excluded responsive to the states of respective *FET switches Q1a, Q1b, Q2a, Q2b, Q3a, and Q3b*. *Capacitor C1*, *resistors R1* and *R2*, and the *FET switches Q1a, Q2a, and Q3a* -- that when active switch in the respective capacitive elements to be measured, -- are all connected to one another at a *first node 1010*, which is connected to the *input 1012* of a *voltage follower U1*. The *output 1014* of the *voltage follower U1* is operatively coupled to *FET switches Q1b*,

$Q2b$ , and  $Q3b$  that when active, switch out the respective capacitive elements so as to not be measured. The activation of the *FET switch* elements of *FET switch* pairs  $Q1a$  and  $Q1b$ ,  $Q2a$  and  $Q2b$ , and  $Q3a$  and  $Q3b$  are respectively mutually exclusive. For example, if *FET switch*  $Q1a$  is activated, or closed, then *FET switch*  $Q1b$  is deactivated or open. A capacitive element being measured adds to the capacitance at the first node, thereby affecting the strength of the signal at the *input 1012* to the *voltage follower U1*. A capacitive element not being measured is disconnected from the first node by its respective first FET switch element, and connected to the *output 1014* of the *voltage follower U1* by its respective second FET switch element, wherein, in accordance with the characteristics of the associated operational amplifier of the *voltage follower U1*, the *output 1014* of the *voltage follower U1* follows the signal of the first node without that respective capacitive element connected, and *voltage follower U1* provides a current through the associated capacitive element through the second respective FET switch element. Moreover, when the respective second FET switch element is activated, the source and drain of the respective first FET switch element are separately coupled to the respective operational amplifier inputs, so that to

each is applied the same potential, thereby eliminating the effect of the capacitance of the respective first FET switch on the capacitance measurement.

[0055] The *output 1014* of the *voltage follower U1* is then coupled to a *second bandpass filter 1016* of the same pass band as the *first bandpass filter 1004*, the output of which is detected by a *detector 1018* comprising *diode D1*, *resistor R3* and *capacitor C2*, and filtered by a *first low pass filter 1020*. The *output 1022* of the *first low pass filter 1020* has a DC component corresponding to the capacitance at the *first node 1010*. This DC component is optionally filtered by an optional *blocking capacitor C3*, and the resulting signal is filtered by a *second low pass filter 1024* to provide an *amplitude signal 1026* representative of the amplitude of the oscillating signal at the *first node 1010*, which is related to the total capacitance at that location. The *blocking capacitor C3* is adapted so as to provide for a transitory measurement of the *amplitude signal 1026*.

[0056] The *first oscillating signal 1006* is also operatively coupled to a *first comparator U3* that generates a *first square wave signal 1028* with a duty cycle of, for example, about 50 percent. The *output 1014* of the *voltage follower U1* is also operatively coupled to a *second comparator U4* that generates a *second*

*square wave signal 1030* with a duty cycle of, for example, about 50 percent. The *first 1028* and *second 1030 square wave signals* are operatively coupled to a logical exclusive OR gate, which, for *first 1028* and *second 1030 square wave signals* each of 50 percent duty cycle, provides a *third square wave signal 1032* having a duty cycle that varies with the phase difference between the *first oscillating signal 1006* and the *output 1014* of the *voltage follower U1*, where in the duty cycle varies between 0 and 100 percent as the phase difference varies between 0 and 180 degrees. The *third square wave signal 1032* is filtered by a *third low pass filter 1034*, the output of which is buffered by *voltage follower U6*. A *blocking capacitor C7* passes the AC component of the output from the *voltage follower U6*, which is filtered by a *fourth low pass filter 1036*, so as to provide *aphase signal 1038* representative of the phase shift to the *first oscillating signal 1006* caused by the elements that are operatively coupled to the *first node 1010*.

[0057] In operation, a *microprocessor U2* controls the activation of *FET switches Q1a, Q1b, Q2a, Q2b, Q3a, and Q3b*, for example in accordance with the control logic illustrated in *Fig. 8b*. With the *first reference capacitor CR1* switched in by *microprocessor U2*, i.e. with *Q2a* activated and *Q2b* deactivated, the con-



troller measures a first amplitude and a first phase. Then with the *second reference capacitor CR2* also switched in by *microprocessor U2*, the controller measures a second amplitude and a second phase corresponding to an incremental increase of capacitance at the first node by the capacitance of *capacitor CR2*. With this information, the controller can compute a sensitivity factor in Volts/pico-Farad from the amplitude measurements given the known values of capacitance of *capacitors CR1* and *CR2*, and an associated sensitivity factor for phase from the phase measurements. Then, the *microprocessor U2* switches out the *first CR1* and *second reference capacitor CR2*, switches in the *sensor electrode 40*, measures a third amplitude and a third phase, and calculates the capacitance and associated phase of the *sensor electrode 40* using the calculated sensitivity factors. The *controller 74* compares this capacitance, and possibly the associated phase, with a threshold so as to discriminate a normally seated occupant from other seat occupancy conditions. In one embodiment, the phase and amplitude are used to compensate for seat wetness, and a compensated measure is compared with a threshold for purposes of occupant discrimination. If a normally seated occupant is present, the *safety restraint actuator 80* is actuated respon-

sive to the detection of a crash by the *crash detector 78*.

Whereas *Fig. 8a* illustrates the *microprocessor U2* and *controller 74* as separate elements that communicate with one another, alternate arrangements are possible. For example, both may be combined in one controller, or the microprocessor may be adapted to sense the amplitude and phase measurements, calculate the capacitance of the capacitive sensing pad and adjust the associated phase measurement, and then output the capacitance value and associated phase measurement to the *controller 74*.

[0058] The *sensor electrode 40*, mounted in the *seat 14*, is modeled as a *first capacitance CS1* in parallel with a series combination of a *second capacitance CS2* and a *resistance RS*, wherein the *resistance RS* is inversely related to the wetness of the seat. The capacitance of the *electric field sensor 12* is dominated by *CS1* for a dry seat, but becomes affected by *CS2* and *RS* as the wetness of the seat increases. The values of capacitance for *capacitors C1, CR1, and CR2* are adapted to maximize the dynamic range of the capacitance measurement over the range of expected capacitances of the *electric field sensor 12*.

[0059] The capacitance of the *electric field sensor 12* can be also measured by other means of measuring capacitance, as

for example given in *the Standard Handbook for Electrical Engineers 12<sup>th</sup> edition*, D.G. Fink and H. W. Beaty editors, McGraw Hill, 1987, pp. 3-57 through 3-65 or in *Reference Data for Engineers: Radio, Electronics, Computer, and Communications 7<sup>th</sup> edition*, E.C. Jordon editor in chief, Howard W. Sams, 1985, pp. 12-3 through 12-12, both included herein by reference.

[0060] *Figs. 9a and 9b* illustrate several other embodiments for various aspects of the *electric-field-sensor circuit 130*, wherein *Fig. 9a* illustrates an amplitude sensing portion of the *electric-field-sensor circuit 130* and *Fig. 9b* illustrates a phase sensing portion of the *electric-field-sensor circuit 130*, wherein the combination of amplitude and phase information can be used to account for seat wetness.

[0061] For example, the elements to be sensed at the *first node 1010* can be coupled via an *analog demultiplexor 1402*, such as a CD4051 from Texas Instruments, wherein under control of the *microprocessor U2*, the elements to be sensed are coupled, one elements at a time, to the *first node 1010* by the *analog demultiplexor 1402*. For example, *first CR1a* and *second CR2a reference capacitors* and a capacitive sensor are each operatively connected to distinct analog inputs of the *analog demultiplexor 1402*, and are operatively connected

mutually exclusively -- to the *first node 1010* by the *analog demultiplexor 1402*. Accordingly, with this arrangement, the calibration process differs from that illustrated in *Figs. 8a-b* for which two reference capacitors can be simultaneously operatively connected to the *first node 1010*. A plurality of *analog demultiplexors 1402* may be used if more analog channels are required, in which case a separate set of reference capacitors, for example *CR1b* and *CR2b*, may be used with each separate *analog demultiplexor 1402* to compensate for variations amongst the various *analog demultiplexors 1402*.

[0062] As another example of an alternate embodiment, an *inductor L1* can be placed between the *sensing node 1010* and the elements to be sensed in order to reduce the effects of electromagnetic interference.

[0063] As yet another example of an alternate embodiment, a *D/A converter 1404* under control of the *microprocessor U2* may be used to cancel offsets in the associated amplitude signal, wherein the output from the *D/A converter 1404* is operatively connected to an *inverting amplifier 1406*, and is subtracted from the *filtered detected amplitude signal 1408*. Similarly, a *D/A converter 1410* under control of the *microprocessor U2* may be used to cancel offsets in the associ-

ated phase signal, wherein the output from the *D/A converter 1410* is operatively connected to an *inverting amplifier 1412*, and is subtracted from the *filtered detected phase signal 1414*. By canceling the respective offsets in the amplitude and phase signals, the associated circuit gains can be increased so as to increase the dynamic range of the respective signals.

[0064] As yet another example of an alternate embodiment, a *logical OR gate 1416* may be used instead of an exclusive OR gate to form the *third square wave signal 1418* representing the detected phase signal. The *logical OR gate 1416* provides an inherent DC bias to the output signal, whereby for square wave input signals of 50 percent duty cycle, the output of the *logical OR gate 1416* varies from 50 percent to full scale as phase difference varies from 0 to 180 degrees.

[0065] As yet another example of an alternate embodiment, a *super diode detection circuit 1420* may be used for detecting the signal amplitude.

[0066] Another method for making a capacitance measurement that can similarly be used to account for seat wetness is to use a peak detector and integrator to identify characteristics of an isolated square pulse, as illustrated by the cir-

cuit shown in *Fig. 10*. The pulse generator sends a square wave pulse through a low pass filter which slows the rise of the pulse in order to reduce ringing that would otherwise result from the inductance of the sensor. When a pulse is sent into the bridge circuit comprising *capacitor C10* and the at least one *sensor electrode 40*, the amplitude and shape of the pulse at the sensing node depends on the sensor's impedance to ground. *Resistor R17* is a relatively small impedance (compared to either *capacitor C10* or the sensor) and reduces the ringing after the rising edge. If the pulse length is short and the sensor is an ideal capacitor to ground, then the output will have essentially the same shape as the input pulse, but a lower amplitude. If the sensor has a complex impedance then the shape of the output pulse will vary depending on the components of the impedance. Conductance from the sensor to ground, as a result of *resistance  $R_s$*  of the *sensor electrode 40*, causes a decreased amplitude and a decay of the voltage to ground. This decay can be used to identify the affect of water on the seat.

[0067] Characteristics of the output pulse, such as the peak and the integral, can be used to identify conductance to ground from the sensor, as illustrated by the circuit

shown in *Fig. 11*. The input pulse is a TTL level square pulse that is filtered to increase the rise time of the leading positive edge. The setting of the rise time is a compromise between immunity to the wet seat condition and ringing in the signal as a result of the inductance at the sensor. Resistors can be placed in the measurement circuit to reduce this ringing.

[0068] Referring to *Fig. 12*, the *occupant sensor 10* can be used to distinguish infants or children in rear facing infant seats, child seats or booster seats, from adults, on the basis that the *child 200* therein does not have a large surface of its body very near to the *seat bottom 18* and the *sensor electrode 40* contained therein. For example, for the *electric field sensor 12* providing a signal responsive to the capacitance of a *sensor electrode 40* thereof, a normally seated occupant provides a substantially larger increase in capacitance relative to an empty seat, than does a *rear facing infant seat 202*. The *occupant sensor 10* can discriminate a *rear facing infant seat 202* (RFIS), or generally a child seat, from an adult because the *child 200* in a *rear facing infant seat 202* does not have a large surface of its body very near to the *seat bottom 18* and the *sensor electrode 40* contained therein. The *seating contour 204* inside the *rear facing infant seat 202* is such that the

buttocks of the *child 200* are closest to the *seat bottom 18* of the *seat 14*. Usually there is a significant *gap 206*, up to several inches, between the *child 200* and the *seat bottom 18* of the *seat 14*. Since child seats are typically made of plastic, the seats themselves are not sensed directly by the *electric field sensor 12*. Even for a *rear facing infant seat 202* for which the *gap 206* between the *child 200* and the *seat bottom 18* of the *seat 14* is relatively small, the inside *seating contour 204* still creates a significant gap between the at least one *first electrode 26* and all parts of the *child 200* except the buttocks. Since only a small portion of the surface of the *child 200* is near to the *sensor electrode 40*, the capacitance measured by the *electric field sensor 12* is relatively low, and more particularly, less than the threshold capacitance,  $C_{\text{norm}}$  for detecting a normally seated adult occupant.

[0069] Referring to *Fig. 3* -- illustrating an example of a *sensor electrode 40* that is electrically isolated from the *heating element 34* in accordance with the embodiments of the *occupant sensor 10* illustrated in *Figs. 1* and *2* -- the *sensor electrode 40* is arranged so as to define a *electrode-less region of reduced sensitivity 208* located proximate to a portion of an infant or child that is closest to the *seat 14* when the infant or child is seated in an infant, child, or booster seat,



and the infant, child, or booster seat is placed on the *seat 14*. The *sensor electrode 40* so adapted exhibits reduced sensitivity to an infant or child that is closest to the *seat 14* when the infant or child is seated in an infant, child, or booster seat, and the infant, child, or booster seat is placed on the *seat 14*. Accordingly, the increase in capacitance responsive to a normally seated occupant seated on a *seat 14* incorporating a *sensor electrode 40* illustrated in *Fig. 3* would be substantially greater than the corresponding increase in capacitance for an infant or child seated in an infant, child, or booster seat placed on the *seat 14*. For example, the electrode-less *region of reduced sensitivity 208* may be located on the *seat bottom 18* approximately 200 to 325 millimeters away from the *seat back 24*.

[0070] Referring to *Fig. 13* -- illustrating an example of a *heating element 34* of a *seat heater 26* utilized as a *sensor electrode 40* in accordance with the embodiments of the *occupant sensor 10* illustrated in *Figs. 4-7* -- the *heating element 34* is arranged -- similar to the *sensor electrode 40* illustrated in *Fig. 3*, and with similar effect -- so as to define an electrode-less *region of reduced sensitivity 208* proximate to a central region of the *seat bottom 18* located proximate to a portion of an infant or child that is closest to the *seat 14* when the

infant or child is seated in an infant, child, or booster seat, and the infant, child, or booster seat is placed on the seat 14.

[0071] One potential limitation with the arrangement illustrated in Fig. 13 is that the *region of reduced sensitivity 208* illustrated as being void of a *heating element 34* -- would receive less heat than portions of the *seat 14* that incorporate the *heating element 34*.

[0072] An *occupant sensor 10* utilizing a *heating element 34* of a *seat heater 26* as a *sensor electrode 40*, may be adapted to incorporate a *region of reduced sensitivity 208*, without affecting the distribution of heat, by shielding that portion of the *heating element 34* within the *region of reduced sensitivity 208* using an electrode located either between the *heating element 34* and the seating region of the seat, or adjacent to the *heating element 34*, extended across the *region of reduced sensitivity 208* and operatively coupled to the *driven shield signal 36*.

[0073] Whereas the *occupant sensor 10* has been illustrated with a single *seat heater 26* located in the *seat bottom 18*, it should be understood that the *occupant sensor 10* may be adapted to cooperate with a plurality of *seat heaters 26* in a *seat 14*, for example, separate *seat heaters 26* in the *seat bottom 18* and in the *seat back 24*. The respective *heating elements 34*

may either be incorporated in separate associated *electric field sensors 12*, with either distinct or shared associated circuit elements, or operatively connected to one another in a single combined *electric field sensor 12*.

[0074] While specific embodiments have been described in detail in the foregoing detailed description and illustrated in the accompanying drawings, those with ordinary skill in the art will appreciate that various modifications and alternatives to those details could be developed in light of the overall teachings of the disclosure. Accordingly, the particular arrangements disclosed are meant to be illustrative only and not limiting as to the scope of the invention, which is to be given the full breadth of the appended claims and any and all equivalents thereof.

[0075] **WE CLAIM:**